Review of the Propagation Characteristics in the 28 and 40 GHz Freqeuncy Bands for LMDS Applications

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The following analysis was prepared at the request of Hughes Communications Galaxy, Inc. for inclusion in its Comments to the Federal Communications Commission on the pending proposal to make frequency bands above 40 GHz avialable for commercial services.

The Commission has expressed its belief that the uses of the millimeter spectrum are likely to be technically and operationally similar to those contemplated in the 28 GHz band for the LMDS service.[1] We have analyzed the propagation differences between the 28 GHz and the 40.5-42.5 GHz bands and the effects of those differences on one of the LMDS system designs that has been proposed at 28 GHz. We conclude that the 40.5 to 42.5 GHz band can provide essentially the same performance characteristics that are currently proposed for typical LMDS systems in the 28 GHz band.[2]

The transmission characteristics of the 40.5 to 42.5 GHz band are determined by the same propagation effects that are present in the 28 GHz band.[3] The major propagation factors affecting communications links in both the 28 or 40 GHz bands are produced by rain, by blockage from foliage, and by reflection and diffraction from buildings or structures. The effects of each of

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[1] Docket No. 94-124, at paragraph 23.

[2] Suite 12 performance characteristics as reported in "Report of the LMDS/FSS 28 GHz Band Negtiated Rulemaking Commitee," Appendix 6, September 23, 1994.

[3] See Sec 2.6, L. J. Ippolito, "Radiowave Propagation in Satellite Communications, *Van Nostrand Reinhold*, New York, 1986.

these factors on system performance are well understood and estimates of performance can be reliably developed for typical systems in either of the two bands. A summary of each of the three propagation factors and their relative impact on the 28 and 40 GHz bands follows.

Rain Effects Signal attenuation due to rain at 41.5 GHz will be about 2.7 dB/mi greater than at 28.5 GHz, for 99.9%-of-the-year link availability, for the New York, NY climate region.[4] The additional rain losses on the 40 GHz freqeuncy band can be overcome by reasonable adjustments to the LMDS equipment parameters. Consider, by way of example, the design of one proposed 28 GHz LMDS system which specifies a 100 watt transmit power, 10 dB hub transmit antenna gain, and 6.9 inch subscriber receiver antenna. This parameter combination is claimed to yield a high quality picture at a typical subscriber site at the edge of a 3 mi radius cell in New York, for at least 99.9% of the year, with a 7 dB backoff and a multiplex of 50 FMTV channels.[5] Three examples of adjustments to the above 28 GHz LMDS system parameters that would allow the same performance in th 40 GHz band are: (a), keep antenna sizes and all other system parameters the same, and accept a slightly lower signal availability at the edge of coverage,(b), increase the hub transmit antenna gain, or, (c), increase the subscriber unit antenna size. Each of the three alternatives are briefly discussed below.

(a) The first alternative involves keeping all system elements

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[4] Calculation for Crane Region D2, and the Crane Global Model, using ITU-R polarization dependent attenuation coefficients, and vertical linear polarization. See "Propagation Effects Handbook for Satellite Systems Design, NASA Reference Publication 1082(04), Feb 1989.

[5] Suite 12 system characteristics, as reported in " Report of the LMDS/FSS 28 GHz Band Negtiated Rulemaking Commitee," Appendix 6, September 23, 1994.

essentially unchanged in size and in power level, and accepting a slightly lower signal availability at the outer edges of the cell area, in return for a system with similar components and costs. An LMDS system designed for a 99.9% availibility at 28.5 GHz would experience a reduction to about 99.84% if operating at 41.5 GHz with the same system parameters (cell size, antenna aperture sizes, transmit power, etc.). These levels correspond respectively to 8.76 hrs/year at 28.5 GHz and 14.0 hrs/year at 41.5 GHz. If we assume that the LMDS service is used on average 7 hrs/day, then the periods of slightly degraded performance would only differ by about 92 minutes over a year between the 28.5 and 40.5 GHz LMDS systems, and then only for subscribers at the edge of the cell.

This slightly lowered availability would still be better than industry standards for delivery of video programming. The European 40 GHz MVDS system acceptable performance requirement is set at 99% <u>of the worst month</u>[6], which corresponds to a 99.7% level on an annuual basis (26.3 hrs/year)[7]. A 41.5 GHz LMDS system designed to the 99.84% acceptable level of performance would therefore perform <u>better</u> than the European 40 GHz MVDS system specification (by about 12.3 hours per year). Moreover, the broadcast satellite service industry (in both European and North American markets) has deployed systems that are designed for a 99.7% link availability which are not only viable but have attracted millions of subscribers. It therefore is reasonable to conclude that similar availability levels for the LMDS would be no deterrence to system acceptance.

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[6] See, for example, Report 40GWG(94)12 of the <u>40 GHz MVDS Working Group</u>, Radiocommunications Agency, U.K., 4 October 1994.

[7] See Recommendation ITU-R PN.841, "Conversion of Annual Statistics to Worst-Month Statistics," Geneva, 1992.

(b) The same system performance achieved at 28 GHz, with the same cell radius, can be achieved in the 40 GHz band with the same transmit power (100 watts), the same subscriber unit antenna size (6.9 in diameter), and a hub antenna gain increase from 10 dB to about 18 dB. This additional gain can be achieved by a modification of the antenna structure, with virtually no additional cost, since active components are not involved.

(c) The third alternative for achieving the same performance in the 40 GHz band with the same cell radius can be accomplished by keeping the hub antenna size the same and increasing the user subscriber antenna size from about 6.9 inches to about to about 12 inches. This design could provide additional benefits because the narrower user antenna beamwidth leads to reduced interference and improved sharing and frequency reuse.

Another important consideration related to the effects of rain on propagation is the variation of rain loss with location. The path loss for the Miami region, for example, is significantly higher than for New York, for the same link availability level (8.6 dB/mi vs 3.6 dB/mi at 28.5 GHz, and 99.9% availability)[8]. The variation of rain loss with climate can be a more significant factor than the variation of rain loss with frequency of operation: the rain loss in Miami at 28 GHz <u>exceeds</u> the rain loss in New York at 41.5 GHz, for the same availability level. It is for this reason that the cell sizes proposed for cities with high rainfall are much smaller than for those cities with lower rainfall. A viable LMDS system designed for operation throughout the continental U.S. would require more system design flexibility to adapt to regional variabilities than it would to change from the 28 to the 40 GHz frequency band.

[8] Calculation for Crane Region E, see Note 4.

It is important to note that the performance levels discussed here are not "loss-of-service" levels, but are levels where performance falls below a specified level of ideal picture quality. Video pictures that are slightly below the ideal level still would be viewable most of the time. Actual loss of service would occur for much shorter time periods, and would depend on the design of the receiver and signal enhancememnt techniques employed in the LMDS system design.

One final point about rain effects: cross polarization interference (depolarization) can also be induced by rain. This interference occurs with the introduction of undesired noise energy in the frequency band where the desired signal is present. Cross polarization interference levels experienced for the rain rates at the link availability levels discussed above, however, are significantly below desired signal levels (by 30 dB or more), in <u>either</u> the 28 or 40 GHz frequency bands. Therefore, rain depolarization is not a problem for LMDS at either of the bands under discussion.

Foliage Effects Foliage loss introduces significant path loss at all frequencies above 10 GHz. Direct measurements of signal attenuation through leafy and non-leafy foliage, at frequencies of 9.6, 28.8, and 57.6 GHz,[9] leads to the following observations regarding the 28 and 40 GHz bands and LMDS systems: the 40 GHz band will exhibit about 10% higher foliage attenuation than at 28 GHz for both leafy and non-leafy conditions, however, in all cases, foliage loss from passage through as few as two trees significantly exceeds 10 dB and often exceeds 20 dB.

It is reasonable to conclude that very little intervening foliage

[9] See F. Schwering, E.J. Violette, R.H. Espeland, "Millimeter-wave propagation in vegetation: Experiments and Theory," *IEEE Trans. Geoscience and Remote Sensing*, Vol 26, No. 3, May 1988.

will be tolerable for viable LMDS service in either band, and the differences in foliage loss between the 20 and 40 GHz bands are inconsequential.

Reflection and Diffraction Effects of Buildings and other Structures Radio signals at the millimeter wavelenghs under consideration here generally travel in straight lines. As a result, receiving sites that do not have a clear line-of-sight (LOS) path from the transmitter cannot receive the signal unless it is; a) reflected or "bounced" from a structure that is in LOS of the transmitter, or, b) diffracted or "bent" around the obstacle in the LOS path. A comparison of the reflection and diffraction effects of buildings on transmissions in the 28 and 40 Ghz bands has been carried out by two analytic methods: classical Fresnel-Kirchoff infinite knife-edge diffraction theory[10], and the uniform geometric theory of diffraction (UTD)[11]. The UTD model was applied using reflection loss values obtained from measurements made on several types of buildings in an urban environment.[12]

The results of the two approaches are in agreement and lead to the following observations: diffraction into the geometric "shadow" region behind a building occurs in both frequency bands,

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[10] See Recommendation ITU-R PN.526-3, "Propagation By Diffraction," ITU, Geneva, 1992.

[11] See R.G. Kouyoumjian and P. Pathak, "A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface,", *Proc. IEEE*, Vol. 62, No. 11, pp. 1448-1461, Nov. 1974, and, W.D. Burnside and K.W. Burgener, "High Frequency Scattering by a Thin Lossless Dielectric Slab," *IEEE Proc. on Antennas and Propagation*, Vol. AP-31, No. 1, pp. 104-110, Jan. 1983.

[12] See E.J. Violette, R.H. Espland, R.O. DeBolt, and F. Schwering, "Millimeter-wave propagation at street level in an urban environment," *IEEE Trans. Geoscience and Remote Sensing*, Vol. 26, No. 3, May 1988.

and the signal levels at any point in the shadow region are similar. The signal level decreases extremely rapidly as one moves into the shadow region, and the shadow boundary region (i.e., the region where diffraction makes non-line-of-sight operation possible) is very small at either frequency.

Reflections from buildings can also yield usable signals at receiving sites that operate in a shadow region, however both analytic approaches discussed above, confirmed by recent laboratory measurements[13], demonstrate that the levels of the reflected signal at 40 GHz are only 1 to 3 dB less than those at 28 GHz. Therefore, in regions where reflected non-LOS transmissions are available at 28 GHz, they would also be available at 40 GHz, with very little impact on performance.

Depolarization will result from scattering or reflection from rough surfaces, however depolarization measurements from UHF to 55 GHz show no discernible dependence on frequency of operation, under similar multipath conditions.[14] This type of depolarization will result in interference levels which are 10 to 20 dB below the desired signal level for either the 28 or 40 GHz bands.

Conclusions A review of the major propagation characteristics in the 28 and 40 GHz bands, with emphasis on their effects on LMDS performance, was accomplished. The effects of rain, foilage, and reflection and diffraction from obstructions were discussed. The

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[13] See description of laboratory measurements conducted at NASA's Lewis Research Center, for reflections from concrete block, metal, wood, and glass, provided in NASA's Comments to ET Docket No. 94-124 RM-8308, dated January 30, 1995.

[14] See, for example, H.J. Thomas, G.L. Siqueira, R.S. Cole, "Polarization diversity for urban millimetric mobile radio communications: Comparison of initial propagation measurement results with prediecion," *Proc. of 42nd IEEE Veh. Technol. Conf.*, Denver CO, May 1992.

impact on signal attenuation and depolarization were quantified to access system performance in the 28 and 40 GHz bands. We conclude that the 40 GHz band can provide essentially the same performance characteristics as those currently proposed for typical LMDS systems in the 28 GHz band, with reasonable adjustments to LMDS system parameters.

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Biography

LOUIS J. IPPOLITO
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EXPERIENCE SUMMARY:

Over thirty years experience in radiowave propagation studies and analysis, and the development, design, and implementation of satellite and terrestrial communications systems. Extensive background in satellite communications systems, propagation effects on space communications, frequency allocation and spectrum management involving telecommunications systems, optical communications, direct broadcast satellites, mobile communications, and supporting technologies. Contributions to national scope government and civil space programs, including the Advanced Communications Technology Satellite (ACTS), the Tracking and Data Relay Satellite (TDRS), the INTELSAT system, Space Station, and FAA National Airspace System communications.

Dr. Ippolito is a recognized international expert on the effects of the Earth's atmosphere on radiowave communications. He is the author of over fifty technical publications, including the books Radiowave Propagation in Satellite Communications Systems, *Van Nostrand Reinhold*, 1986, and, Propagation Effects Handbook for Satellite Systems Design, *NASA JPL Ref. Pub. 1082(4)*, February 1989.

EDUCATION:

D.Sc. - The George Washington University, May 1977
M.S.E. - The George Washington University, February 1966
B.S.E.E. - Newark College of Engineering (NJIT), June 1962
(all degrees in Electrical Engineering)

EMPLOYMENT HISTORY:

Jun'89 to Present:	Technical Director and Chief Scientist Stanford Telecom (STel)
Mar'87 to Jun'89:	Senior Advisory Engineer Westinghouse Electric Corporation
Dec'83 to Mar'87:	Senior Scientist and Director of Advanced Studies CONTEL Spacecom
Nov'79 to Dec'83:	Program Manager Communications Division NASA Headquarters

May'78 to Nov'79:	Senior Engineer Communications Systems Analysis Office NASA Goddard Space Flight Center
Jan'72 to May'78:	Principal Investigator NASA Goddard Space Flight Center
Jun'62 to Jan'72:	Electronics Engineer R.F. Systems Branch NASA Goddard Space Flight Center

HONORS AND AWARDS:

NASA Quality Increase Award, for accomplishments in the management of the Advanced Communications Technology Satellite (ACTS) experiments program, September 1983.

NASA Quality Increase Award, for accomplishments in the management of NASA's propagation and applications experiments programs, July 1981.

Benjamin Franklin Award, The Engineers Club of Philadelphia, February 1976.

NASA Quality Increase Award, for accomplishments on the ATS-6 program, March 1975.

NASA Exceptional Performance Award, "In recognition of Scientific Excellence in the Reporting and Investigation of Millimeter Wave Experiments Involving Earth-Space Communications," November 1972.

NASA Quality Increase Award, for accomplishments on the ATS-5 program., August 1972.

DOCTORAL DISSERTATION:

"Scattering in Discrete Random Media with Implications to Propagation Through Rain," The George Washington University, School of Engineering and Applied Science, May 8, 1977.

PROFESSIONAL SOCIETIES:

Institute of Electrical and Electronics Engineers (IEEE) - Fellow

International Telecommunications Union - Appointed Member, ITU-R Study Groups 2,3,4,7.

International Radio Science Union (URSI) - Elected Member.

American Institute of Aeronautics and Astronautics (AIAA) - Member.

MAJOR PUBLICATIONS (since 1970):

1. Ka Band Propagation Statistics at White Sands New Mexico, with G. Feldhake, *National Radio Science Meeting*, Boulder, Jan 5, 1995.

2. Modeling and Prediction of Atmospheric Effects from Satellite Beacons, *SPIE Conference on Atmospheric Propagation and Remote Sensing* III, Orlando, April 1994.

3. Propagation Considerations for Emerging Satellite Communications Applications, with T.A. Russell, *Proceedings of the IEEE*, Vol 81, No 6 June 1993.

4. ACTS Propagation Measurements Program for New Ka-Band Applications, *ACTS Conference '92*, Washington, DC, November 1992.

5. Propagation Effects Handbook for Satellite Systems Design, *NASA JPL Ref. Pub. 1082(4)*, Washington, D.C., 4th Edition, February 1989.

6. Radiowave Propagation in Satellite Communications Systems, *Van Nostrand Reinhold*, New York, 1986.

7. Rain Attenuation Prediction for Communications Satellite Systems, *AIAA 10th Communications Satellite Systems Conference*, Orlando, FL, March 1984.

8. The Advanced Communications Technology Satellite (ACTS) Experiments Program, *EASCON'83 Conference*, Washington, D.C., September 1983.

9. The Effects of Rain on System Performance for the NASA 30/20 GHz Experimental Satellite, *ICC'82*, Philadelphia, PA, June 1982.

10. The ATS-1 Experience - A Decade of Satellite Communications in the Pacific Hemisphere, *Pacific Telecommunications Conference*, PTC'82, Honolulu, HA, January 1982.

11. Radiowave Propagation for Space Communications Systems, *Proceedings of the IEEE*, Vol. 69, No. 6, pp. 697-727, June 1981.

12. Cumulative Statistics of 11.7 and 28.65 GHz Rain Attenuation From CTS and COMSTAR Satellite Beacon Measurements, *International IEEE and National Radio Science Meeting*, Seattle, WA, June 1979.

13. Rain Attenuation Prediction at 10 and 100 GHz from Satellite Beacon Measurements, *EASCON'78*, Arlington, VA, September 1978.

14. Rain Attenuation and Depolarization in Millimeter Wave Space Communications, *IEEE Antennas and Propagation Society*, McLean, VA, November 1977.

15. A Millimeter Wave Communications Experiment for Spacelab, with R. Kaul, *National Telecommunications Conf.*, Dallas, TX, Nov 1976.

16. ATS-6 Millimeter Wave Propagation and Communications Experiments at 20 and 30 GHz, *IEEE Transactions on Aerospace and Electronics Systems*, Vol. AES-11, No. 6, pp. 1067-1082, November 1976.

17. Space Shuttle Millimeter Wave Experiment, with W. Kummer and K. Lewis, *IEEE Intercon'75*, New York, April 1975.

18. Large Millimeter Wave Aperture Antenna Experiment for Space Shuttle Applications, *NTC'74, National Telecommunications Conference*, San Diego, CA, December 2, 1974.

19. Attenuation and Wideband Coherence Measurements at 20 and 30 GHz with the ATS-6 Satellite, *1975 Fall URSI/USNC Meeting, Boulder*, CO, October 1974.

20. Propagation and Interference Measurements with the Communications Technology Satellite, *1973 International IEEE/G-AP Symposium and USNC/URSI Meeting*, Boulder, CO, August 1973.

21. Millimeter Wave Space Communications with the ATS-E Satellite, *1973 International Microwave Symposium*, Boulder, CO, June 1973.

22. Millimeter Wave Propagation Measurements from an Orbiting Earth Satellite, *IEE Conference on Propagation of Radio Waves at Frequencies Above 10 GHz*, London, England, April 1973.

23. Correlation Measurements of 15.3 GHz Attenuation and Ground Rainfall Rate for an Earth-Satellite Path, *1972 International IEEE/G-AP Symposium and Fall USNC/URSI Meeting*, Williamsburg, VA, December 1972.

24. Millimeter Wave Space Communications, Recent Experimental Results and Present Development Programs, *1972 National Telecommunications Conference*, Houston, TX, December 1972.

25. The 20 and 30 GHz Communications Systems for the ATS-E Millimeter Wave Experiment, *IEEE International Conference on Communications, ICC'72*, Philadelphia, PA, June 1972.

26. Summary and Evaluation of the ATS-5 Millimeter Wave Experiment, *1972 USNC/URSI Spring Meeting*, Washington, DC, APril 14, 1972.

27. ATS-F Millimeter Wave Propagation Experiment Data Processing, with J.H. Nunnally, *EASCON'71*, Washington, DC, October 1971.

28. Effects of Precipitation on 15.3 and 31.65 GHz Earth-Space Transmission with the ATS-V Satellite, *Proceedings of the IEEE*, Special Issue on Satellite Communications, Vol. 59, No. 2, pp. 189-205, February 1971.

29. Propagation Statistics for 15 and 32 GHz Earth-Space Transmissions from the Applications Technology Satellite (ATS-5), *1970 IEEE/G-AP Symposium and Fall USNC/URSI Meeting*, Columbus, OH, September 15, 1970.

30. Millimeter Wave Propagation Measurements from the Applications Technology Satellite (ATS-5), *IEEE Transactions on Antennas and Propagation*, Vol. AP-18, No. 4, pp. 535-552, July 1970.

31. Millimeter Wave Systems for Space Communications, *ICC'70*, San Francisco, CA, June 8, 1970.

32. Millimeter Waves for Domestic Satellite Systems, *AIAA Third Communications Satellite System Conference*, Los Angeles, CA, April 7, 1970.

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EXHIBIT B

TECHNICAL STATEMENT

This Technical Statement has been prepared for Hughes Communications Galaxy, Inc. ("Hughes") for inclusion in its Comments on the Commission's Notice of Proposed Rulemaking in ET Docket No. 94-124 (the "NPRM").

In the millimeter wave frequency bands that the Commission is proposing to open for commercial use, including 40.5-42.5 GHz, the Commission has proposed to limit the power of licensed transmitters to 16 dBW equivalent isotropically radiated power (EIRP). (NPRM at ¶ 33.) The Commission explained that this limit was "based on: 1) an assumed limit of -20 dBW of transmitter power, which is likely to be typical of commercially-affordable microwave integrated circuits in the near future; and, 2) an antenna gain of 36 dB, which we believe will be typical of economical antennas and transmission systems in the near future." Id.

It appears that the Commission's proposed EIRP limit is based on the assumption that transmitters operating above 40 GHz would employ solid state power amplifiers (SSPAs). However, some proponents of the LMDS systems currently proposed for 28 GHz have indicated their intention to use travelling wave tube amplifiers (TWTAs) in their systems. While the Commission's proposed EIRP limit would be sufficient to accommodate 40 GHz systems that use SSPAs, it would foreclose the use of TWTAs, unless the EIRP limit were normalized to a referenced bandwidth corresponding, for example, to a single TV channel as suggested below.

As set forth in Hughes' Comments, the 40.5-42.5 GHz band can suitably accommodate LMDS systems of the type currently proposed for the 28 GHz band. Hughes has indicated various options for achieving the same, or equivalent, performance at 40 GHz with minimum, or no, changes to the technical parameters of the 28 GHz system designs. These options include:

(a) maintaining the same transmit power (100W), transmit antenna size, cell size, and receive antenna size, but accepting a lower signal availability for a specified television picture quality (Option A);

(b) maintaining the same transmit power (100W), cell size, receive antenna size, and availability, but increasing the transmit antenna gain from 10 to 18 dB (Option B); and

(c) maintaining the same transmit power (100W), cell size, transmit antenna size, and availability, but increasing the receive antenna size from 6.9 to 12 inches (Option C).

To determine the EIRP levels corresponding to these options for comparison with the limit proposed by the Commission for the Licensed Millimeter Wave Service (LMWS), it should be noted that, in the Suite 12/CellularVision 28 GHz LMDS system design used as a "baseline" for comparison purposes:

(1) the 100W (+20 dBW) of transmit power is produced by a TWTA which is "backed off" by 7 dB so that the power fed to the transmit antenna is 20W (+13 dBW), and

(2) this power is used to transmit a multiplex of about 50 television channels occupying a bandwidth of 1000 MHz.

Therefore at 28 GHz, the proposed EIRP is 13 (transmit power) + 10 (antenna gain) = 23 dBW, distributed over a 1000 MHz bandwidth containing fifty TV channels. For the options considered in the 40 GHz band, the corresponding EIRPs would be

(a) 26.3 dBW (Option A)[1];

(b) 31 dBW (Option B)[2]; and

(c) 26.3 dBW (Option C)[1];

each measured over a 1000 MHz bandwidth containing fifty 20 MHz TV channels, and assuming the use of a 100W TWTA in the 40 GHz band.

Alternatively, an LMDS system could use a separate solid state power amplifier (SSPA) for each television channel.[3] Assuming the use of SSPAs, the required transmitter power fed to the antenna in the 40 GHz band would be 20W/50 = 0.4W (-4 dBW) per channel, and the EIRP per transmitter for the three system design options would be:

(a) 9.3 dBW (Option A)[4];

(b) 14 dBW (Option B)[5]; and

(c) 9.3 dBW (Option C)[4];

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1. This is the sum of (i) 13 dBW (transmit power), plus (ii) 13.3 dBW (antenna gain).

   The antenna gain includes the 3.3 dB increase that results from increasing the frequency from 28 GHz to 41 GHz while keeping the physical size of the transmit antenna unchanged.

2. This is the sum of (i) 13 dBW (transmit power), plus (ii) 18 dBW (antenna gain).

3. It is not necessary and it may not be cost effective to use a TWTA at 40 GHz. While SSPAs may be a better alternative for many reasons, including the fact that each channel has an independent transmitter, the licensee should have the flexibility to choose the equipment that best suits its needs.

4. This is the sum of a (i) -4 dBW (transmit power), plus (ii) 13.3 dBW (antenna gain).

5. This is the sum of a (i) -4 dBW (transmit power), plus (ii) 18 dBW (antenna gain).

each spread over a 20 MHz bandwidth.[6]

Using SSPAs where a separate 0.4W transmitter is used for each 20 MHz channel, the LMDS system would easily comply with the 16 dBW limit proposed by the Commission. Using TWTAs where a single transmitter's power is spread over the full 1000 MHz occupied by the 50 channels, the values based on use of a 100W TWTA (backed off 7 dB to 20W) in the 40 GHz band presumably would not comply. Nonetheless, whether it uses fifty SSPAs or a single TWTA, the system would generate the same amount of power distributed in the same way over the same total bandwidth. Therefore, the actual radiation levels over the occupied 1000 MHz are exactly the same, regardless of the power amplifier used, even though only one type of amplifier configuration would appear to comply with the limits.

One way to resolve the apparent contradiction would be to normalize the EIRP limit to an appropriate reference bandwidth such as that occupied by a single television channel. To make sure that the limit would be applicable to the variety of signals that future LMDS systems might transmit (including non-video signals and interactive return links), further study is required.

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January 30, 1995

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6. The Commission's assumption about the power levels that likely will be available from commercially affordable solid state amplifiers in the near term (-20 dBW (0.1W)) is much too conservative.

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EDUCATION

B.A. with honors (Physics), University of California, Berkeley, 1943
Naval Officer Training, USNR Midshipmen's School, Columbia University, 1944
Aviation Radar Officer Training, Naval Radar Schools, Harvard University and MIT, 1944
M.A. with honors (Physics), University of California, Berkeley, 1950
Further graduate studies (Physics, Radio Astronomy, and EE), Cornell University, 1951-1954

PROFESSIONAL EXPERIENCE

Telecommunications Consultant **1988 - present**

- Trained frequency managers in international regulatory procedures for obtaining frequency and orbital position assignments for satellite communication systems, e.g., AIAA Colloquium on Orbit and Spectrum Utilization, Arlington, VA, 1988.
- Helped satellite and terrestrial communication system applicants identify suitable orbital positions and frequency plans, e.g., PacTel Teletrac 1989, LOCSTAR 1990.
- Directed engineering studies of proposed satellite systems and prepared technical filings in response to FCC Notices of Inquiry and Petitions for Rulemaking for major corporate clients and trade associations, e.g., COMSAT, Hughes, USSB, SBCA, 1989-93.
- Represented clients in the development and testing of new standards for satellite and terrestrial high definition television and the associated audio and data services by the Advanced Television Systems Committee (ATSC) and the FCC Advisory Committee on Advanced Television Systems, e.g., COMSAT 1988-91, Hughes 1992-93.
- Organized technical seminars and presented papers at major engineering conferences, e.g., Los Angeles 1989, Geneva 1989, Nicosia 1990, Chicago 1990, Las Vegas 1988-91, Nashville 1988-91, Bangkok 1991, Washington 1992, Acapulco 1992, Singapore 1992, Paris 1992, Budapest 1992, Denver 1992, Honolulu 1993.
- Prepared position papers and technical analyses for and served on U.S. delegation to meetings of CITEL Permanent Technical Committees II (Broadcasting) and III (Telecommunications), e.g., Washington 1991, Mexico City 1992.
- Chaired working groups of FCC's Industry Advisory Committee on WARC preparations, e.g., Working Group D (broadcasting satellite issues) 1988, Group 2B (digital audio broadcasting) 1991.
- Chaired Working Group 2 (Interservice Sharing) of FCC's MSS Above 1 GHz Negotiated Rulemaking Committee, 1993.
- Prepared U.S. delegation position papers and supporting technical analyses on frequency allocation and regulatory issues in preparation for international regulatory conferences, e.g., WARC-ORB-88, WARC-92.
- Served as a U.S. Delegation spokesman and/or advisor on satellite issues at World Administrative Radio Conferences, e.g. WARC-ORB-88 in Geneva, WARC-92 in Torremolinos, WRC-93 in Geneva.
- Chaired or participated in U.S. preparations for meetings of International Radio Consultative Committee (CCIR) Study Groups, Working Parties, and Task Groups, and served as head of U.S. delegation or U.S. spokesman at those meetings, e.g., Plenary Assembly of Study Groups Dusseldorf 1990; Radiocommunication Assembly Geneva 1993; Joint Interim Working Party JIWP 10-11/1 (feeder link planning and satellite sound broadcasting) Sydney 1990; Joint

Interim Working Party JIWP 10-11/3 (high definition television (HDTV) by satellite) Stockholm 1989, Sydney 1990; Extraordinary Meeting on HDTV issues of Study Group 11 (television broadcasting) Geneva 1989; IWP 8/14 (mobile-satellite service) Tokyo 1989, Melbourne 1990; Study Group 8 (mobile services) Geneva 1989; Joint Working Party 10-11S (satellite broadcasting) Geneva 1989 and 1991, Los Angeles 1993, Geneva 1993; Study Groups 10 and 11 (radio and TV broadcasting) Geneva 1992; Joint Interim Working Party JIWP/WARC-92 Geneva 1991.

- Participated in U.S. preparations for meetings of various ITU and CCIR groups concerned with restructuring those organizations and improving their working methods, e.g., ITU High Level Committee 1990-92, ITU Voluntary Group of Experts 1991-93, CCIR Advisory Group on Strategic Review and Planning 1991-93.

COMSAT, Information Systems Division **1985 - 1988**
Director, Requirements Analysis and Spectrum Management

- Directed studies to quantify COMSAT client's satellite coverage and traffic requirements and to identify preferred satellite system designs, frequency plans, and orbital positions to meet these requirements in the face of existing regulatory constraints.
- Managed major COMSAT proposal preparation efforts.
- Coordinated the development of COMSAT's positions on the technical aspects of domestic and international regulatory issues.
- Directed the preparation of supporting technical analyses and filings with FCC.
- Provided management of or representation on industry trade associations, on government advisory committees, and on U.S. delegations to major CCIR Study Groups, Interim Working Parties, and ITU World Administrative Radio Conferences, such as WARC-ORB(85) and WARC-MOB(87).

COMSAT, Satellite Television Corporation **1981 - 1984**
Director, Spectrum Management

- Directed the extensive spectrum engineering studies associated with designing the first U.S. DBS system and obtaining an FCC construction permit for it.
- Coordinated STC's major contributions to the development, ab initio, of domestic rules and policies for the DBS service.
- Chaired a subcommittee of the FCC Advisory Committee on DBS Standards.
- Directed all aspects of STC's contributions to and participation in U.S. preparations for the Region 2 BSS planning conference (RARC-83).
- Served as chairman of the Technical Committee of FCC Advisory Committee on RARC-83.
- Was International Chairman of the CCIR Conference Preparatory Meeting for RARC-83.
- Served as a key spokesman on U.S. delegation to RARC-83.

COMSAT, Office of the Chief Scientist **1977 - 1980**
Manager, CCIR and ITU Affairs

- Developed the technical elements of and supporting analytic studies for COMSAT's position on the technical, allocation, and other regulatory issues of the commercial space services (fixed-satellite, mobile-satellite, and broadcasting-satellite) for the 1979 World Administrative Radio Conference (WARC-79).
- Promulgated and represented that position in response to FCC Public Notices and on FCC Advisory Committees.
- Participated in U.S. efforts to gain international acceptance of the resultant U.S. position prior to the Conference (through intergovernment meetings and ITU seminars).
- Served as a spokesman for the U.S. delegation to WARC-79.

Jet Propulsion Laboratory **1975 - 1977**

Project Manager, NASA Broadcasting Satellite Studies

- Directed engineering studies on all aspects of broadcasting-satellite system design and economic feasibility, including interference problems of sharing with other radiocommunication services.
- Chaired 50-member U.S. CCIR JWG 10-11S in preparing all U.S. inputs to 1976 interim meetings of Study Groups 10 and 11 related to technical characteristics, sharing criteria, and planning methods for the broadcasting-satellite service.
- Chaired 75-member FCC Advisory Committee on preparations for first worldwide broadcasting-satellite planning conference, WARC-77.
- Presented lectures at all three ITU preparatory seminars for developing countries.
- Participated in pre-Conference bilaterals with ten administrations.
- Served on U.S. delegations to 1976 CCIR interim and WARC-77 preparatory meetings.
- Was a delegation spokesman and the international co-chairman of the Technical Committee at WARC-77.

RAND Corporation **1954 - 1974**

Senior Scientist

- Directed systems engineering studies on the application of scatter propagation techniques to tactical and strategic command, control, and communication problems.
- Analyzed the performance characteristics and costs of military telecommunications equipment.
- Developed a detailed performance comparison of analog modulation, multiplexing, and signal processing methods for space communications.
- Prepared a study for NASA on the optimization of systems for the mobile- and broadcasting-satellite services.
- Wrote a major report for NASA on maximizing orbit-spectrum utilization for broadcasting-satellite and fixed-satellite systems sharing the same frequency band.
- Served as broadcasting-satellite spokesman on U.S. delegation to the 1971 World Administrative Radio Conference on Space Telecommunications (WARC-71).
- Took over chairmanship of U.S. CCIR Joint Working Group 10-11S on satellite broadcasting.

RECENT PROFESSIONAL ACTIVITIES

Board of Directors: Society of Satellite Professionals, 1983

Board of Directors: Direct Broadcast Satellite Association, 1984 - 1986

Board of Directors: Satellite Broadcast and Communications Association (SBCA), 1986 - 1991

Chairman: Technical Committee, SBCA, 1986 - present

Chairman: Space Segment Group, SBCA, 1988 - 1991

Chairman: Working Group D (Satellite Broadcasting), FCC Industry Advisory Committee for Space WARC, 1984 - 1988

Chairman: Ad Hoc Working Group 2B (Digital Audio Broadcasting), FCC Industry Advisory Committee for WARC-92

Chairman: U.S. CCIR Joint Working Party 10-11S (Satellite Broadcasting), 1973 - present

U.S. Representative: International Electrotechnical Commission Working Group T, 1986 - present

Editorial Board: COMSAT Technical Review, 1984 - 1988

Editorial Board: IEEE Spectrum, 1984 - 1986

Co-Guest Editor: IEEE Journal on Selected Areas in Communications--Special Issue on DBS, January 1985

MILITARY SERVICE

U.S. Navy: Apprentice Seaman to Lt(jg), 1943 - 1946
Faculty, MIT Radar School, Boston, MA, 1944 - 1945
Staff, Naval Research Lab, Washington, DC, 1945 - 1946

PUBLICATIONS

Over 100 technical reports and papers including recent conference presentations at ICC, Globecom, Eascon, AIAA Satellite Conference, SCUC, and at ITU seminars in Rio de Janeiro, Kyoto, Sydney, Khartoum, Ahmedabad, Lima, Ottawa, Buenos Aires, Geneva, Nicosia, Acapulco, and Budapest. (Publications list available upon request.)

PROFESSIONAL AND HONORARY SOCIETIES

IEEE, AIAA, Phi Beta Kappa, Sigma Xi
Diplôme d'Honneur - CCIR 1991